Application of Remote Sensing in the
Determination of Water Quality in Nebraska Reservoirs

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Project Completion Report

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## Introduction

The purpose of this project has been to determine the feasibility of detecting and quantifying selected water quality parameters in Nebraska reservoirs which are useful for indicating their trophic status. The bulk of the results obtained over the last three years in this project was transmitted earlier to NASA in the form of a Masters' thesis by Mr. Kelly White. The data contained therein will not be duplicated here. One result reported in the thesis and which forms the basis for the present report was that CCT's from Landsat correlated very well with the water quality parameters chlorophyll, turbidity, and suspended solids. However, because the tape of only one overflight with concurrent ground truth was available, it was necessary to collect additional data in order to determine the usefulness of Landsat for measuring specific water quality parameters.

## Methods

In June, July, and August, 1975 ground truth was collected from Lake McConaughy, a 35,000 acre reservoir in western Nebraska, coincident with the overflights of Landsat. Water samples were collected on six different dates and analyzed for turbidity, suspended solids, and chlorophyll, parameters which from our earlier work had correlated well with CCT reflectances. However, on three of the dates for which ground truth was collected the satellites were not operating when they passed over Lake McConaughy, the study site. Consequently the correlations

and regressions reported below were derived from data obtained on only three of the six sampling dates.

The three CCT's corresponding to the ground truth were processed by the University of Nebraska's IBM 360 computer. The radiance values from each of the four spectral bands were printed out in the form of a map of Lake McConaughy. Reflectances in the various bands were then obtained from the map at the appropriate sampling sites. Following our previous protocol, the dependent variables chlorophyll, suspended solids, and turbidity were compared to the independent variables - reflectances in the four bands - by regression analysis. Both multiple and univariate regressions were examined. In order for a regression to be deemed significant we chose the same significance values used in our previous work; a coefficient of determination of .43 for univariate regressions and .60 for multivariate regressions, and a probability of less than 0.05 that the F value would exceed the tabular F value.

## Results

The input data collected from ground truth and CCT reflectances are given in Table 1. The range of suspended solids measured (3-184 mg/l) and the distribution of values within this range are such to allow meaningful regressions. The range of turbidity and chlorophyll concentration is more restricted and is confined to the low end of the scale. Although useful statistics can be derived from the observations it would be desirable to have data of wider scope. The chlorophyll values less than 4 $mg/m^3$ and turbidity values less than 2 FTU, because

Table 1. CCT reflectances and chlorophyll, suspended solids, and turbidity from three stations in Lake McConaughy, summer, 1975.

| Date | Reflectance ($mW/cm^2$) Band 4 | Band 5 | Band 6 | Band 7 | Chlorophyll ($mg/m^3$) | Suspended solids (mg/1) | Turbidity (FTU) |
|---|---|---|---|---|---|---|---|
| 6/19/75 | | | | | | | |
| East | 13.5 | 8.5 | 7.5 | .5 | .001 | 35 | .80 |
| Middle | 15.0 | 9.5 | 5.0 | .3 | .27 | 16 | 1.40 |
| West | 18.5 | 14.5 | 5.5 | 1.0 | 4.07 | 99 | 5.10 |
| 7/7/75 | | | | | | | |
| East | 14.5 | 10.0 | 5.5 | .5 | .03 | 8 | .90 |
| Middle | 17.5 | 12.0 | 6.5 | 1.0 | .40 | 18 | 1.50 |
| West | 24.0 | 20.0 | 10.0 | 1.0 | 5.47 | 183 | 11.30 |
| 7/25/75 | | | | | | | |
| East | 13.5 | 9.0 | 5.0 | .53 | 1.24 | 3 | 1.1 |
| Middle | 15.5 | 10.0 | 4.8 | .01 | 1.54 | 3 | 1.6 |
| West | 23.5 | 19.5 | 10.0 | .5 | 11.49 | 184 | 14.0 |

of the wide confidence limits associated with their measurement, are not very useful in the regressions we have developed. The chlorophyll concentrations measured in Lake McConaughy are typical of oligotrophic lakes even though Lake McConaughy is eutrophic by other parameters.

Table 2 shows the correlation coefficient "r" between the water quality parameters and reflectances in the different spectral bands. In every case band 7 (infra-red) proved to have lower correlation between chlorophyll, suspended solids, and turbidity than did the remaining three bands. In fact, in no instance was the derived regression equation with band 7 reflectances significant by the previous levels of significance we had adopted. On the other hand, the correlations between bands 4, 5, 6, and turbidity and suspended solids are very high indeed. The correlation between these bands and chlorophyll, although not as high, is still very strong. At this point the results would suggest that bands 4, 5, 6 from Landsat CCT would be exceedingly useful for detecting the parameters chlorophyll, suspended solids, and turbidity in lakes and reservoirs. Table 3 gives the univariate regression statistics for significant water quality - band reflectance relationships. The equations in the table will give the value of the parameter in water if reflectance from the appropriate spectral band is inserted at the appropriate place in the equation.

Multiple regression statistics were developed to examine the simultaneous interaction between dependent variables and reflectances in all four spectral bands. To be significant the regressions had to have a coefficient of determination of at least 0.6. Table 4 presents

Table 2. Correlation coefficients (r) between CCT reflectances and water quality parameters.

| Reflectance source | Parameter | | |
|---|---|---|---|
| | Suspended solids | Turbidity | Chlorophyll |
| Band 4 | .9420 | .9515 | .8569 |
| Band 5 | .9629 | .9643 | .8757 |
| Band 6 | .8747 | .8549 | .7386 |
| Band 7 | .4522 | .3178 | .1819 |

Table 3. Univariate regression statistics for significant reflectance - water quality relationships

| Water parameter | Band | F value | Prob. > F | Coeficient of determination | Line Equations* |
|---|---|---|---|---|---|
| Chlorophyll | 4 | 19.3438 | .0032 | .7343 | 0.8089(X) - 11.2527 |
| | 5 | 23.0197 | .0020 | .7668 | 0.7471(X) - 6.6568 |
| | 6 | 8.4004 | .0230 | .5455 | 1.3497(X) - 6.2445 |
| Suspended Solids | 4 | 55.0984 | .0001 | .8873 | 17.6271(X) -243.5568 |
| | 5 | 89.1447 | .0001 | .9272 | 16.2854(X) -143.4724 |
| | 6 | 22.7916 | .0020 | .7650 | 31.6867(X) -149.5407 |
| Turbidity | 4 | 67.0242 | .0001 | .9054 | 1.1835(X) - 16.2603 |
| | 5 | 92.9259 | .0001 | .9299 | 1.0840(X) - 9.4220 |
| | 6 | 19.0050 | .0033 | .7308 | 2.0585(X) - 9.4887 |

* X = reflectance, $mW/cm^2$, from CCT.

Table 4. Multivariate regression statistics for significant reflectance - water quality relationships

| Water parameter | Band | F value | Prob. > F | Coefficient of determination | Line Equations* |
|---|---|---|---|---|---|
| Chlorophyll | 4,5,6,7 | 7.6570 | 0.0389 | .8845 | $-1.3756(X_4)+2.1153(X_5)+0.0789(X_6)-4.2372(X_7)+1.9216$ |
| Suspended Solids | 4,5,6,7 | 29.3317 | 0.0052 | .9670 | $-21.5186(X_4)+32.4514(X_5)+9.6019(X_6)-14.1302(X_7)-30.0667$ |
| Turbidity | 4,5,6,7 | 66.8495 | .0019 | .9853 | $-1.0194(X_4)+1.9656(X_5)+0.4358(X_6)-3.4647(X_7)-3.7173$ |

* $X_4$, $X_5$, $X_6$, $X_7$ are reflectances ($mW/cm^2$) from bands 4,5,6,7

the statistics for these regressions. All four spectral bands were used in the multiple regression even though band 7 contributes little to it. The reflectances from band 7 could be eliminated with no loss in accuracy or precision.

## Discussion

The objective of the research was to confirm our earlier observations that reflectance data from Landsat CCT's correlate very well with certain water quality parameters, especially suspended solids, turbidity, and chlorophyll concentration. The additional data we collected have resulted in even stronger correlations than we reported earlier. However, an unfortunate aspect is that the confidence intervals associated with the regression equations are extremely broad, suggesting that even though the parameters can be detected and measured by remote sensing, the accuracy of the measurements is questionable. Table 5 compares the confidence intervals of our regressions from the Salt Valley Lakes of eastern Nebraska with those developed more recently from Lake McConaughy. The confidence intervals of our most recent data are broader than those we reported earlier. Part of the reason is owing to the uncertainty associated with measuring very low values of chlorophyll and turbidity. For example, depending upon the spectral band, the confidence intervals for chlorophyll vary between 38 and 56% of the value predicted by the regression equation. However, if all chlorophyll values less than 4 $mg/m^3$ are eliminated, the confidence intervals are reduced to a maximum of ±59% of the value predicted by

Table 5. Mean, range, and confidence interval for selected water quality parameters detected in different spectral bands

| | Salt Valley Lakes | | Lake McConaughy | |
|---|---|---|---|---|
| | $\bar{x}$ | Range | $\bar{x}$ | Range |
| Turbidity (FTU) | 20 | 8-32 | 4 | 0.8-14 |
| Chlorophyll ($mg/m^3$) | 76 | 45-109 | 3 | <.01-11 |
| Suspended solids (mg/l) | 41 | 23-58 | 61 | 3 - 184 |
| | Confidence intervals for the spectral bands | | | |
| | Chlorophyll | | Chlorophyll | |
| Band 4 | 15-38% | | 41-400% | |
| Band 5 | 25-63% | | 38-434% | |
| Band 6 | 16-31% | | 61-560% | |
| | Suspended Solids | | Suspended Solids | |
| Band 4 | 23-52% | | 22-119% | |
| Band 5 | 23-85% | | 19-188% | |
| Band 6 | 16-29% | | 36-452% | |
| | Turbidity | | Turbidity | |
| Band 4 | 23-75% | | 21-178% | |
| Band 5 | 33-115% | | 18-437% | |
| Band 6 | 13-31% | | 39-355% | |

the regression equation. Thus, concentrations above 4 $mg/m^3$ can be predicted with an accuracy of ±38-59% of the value calculated with our regression equation. Similarly, the confidence intervals for turbidity vary between 18 and 437% of the predicted value but if those observations less than 2 FTU are eliminated the interval narrows to ±18-138%. Moreover, if band 6 and 7 reflectances are not considered the confidence interval becomes ±18-24% of the predicted value. The data suggest that the small values at the lowermost part of the measured range are seriously affecting the accuracy with which the water quality parameters can be quantified. Thus the lower limits of meaningful detection would appear in our reservoirs to be 4 $mg/m^3$ chlorophyll, 2FTU turbidity, and about 3-5 mg/l suspended solids. The data from the Salt Valley Reservoirs (Table 5) indicate that in concentrations up to 109 $mg/m^3$ chlorophyll, 32 FTU turbidity, and 58 mg/l suspended solids can be measured with fair accuracy. As the concentrations increase the confidence intervals become narrower.

Given the above considerations we conclude that CCT's from Landsat can be used to detect and quantify the water quality parameters suspended solids, turbidity, and chlorophyll. The measurements thus obtained are not precise enough to detect subtle changes in the trophic status of a lake or reservoir or to allow categorization of groups of lakes closely placed along the trophic spectrum. They can, however, be used with confidence we believe, to distinguish between and classify lakes at the ends of the trophic spectrum from oligotrophic to eutrophic.